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## **The Galactic O-Star Spectroscopic (GOSSS) and Northern Massive Dim Stars (NoMaDS) Surveys, the Galactic O-Star Catalog (GOSC), and Marxist Ghost Buster (MGB)**

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**Abstract.** There are several ongoing massive-star (mostly of spectral type O) surveys that are significantly increasing the quality and quantity of the spectroscopic information about these objects. Here we discuss and present results for two of them, GOSSS and NoMaDS. We also discuss recent and future developments on the Galactic O-Star Catalog and announce the upcoming availability of Marxist Ghost Buster, an IDL code that attacks spectral classification (hence the name) by using an interactive comparison with spectral libraries.

### **1. O-star spectroscopic surveys**

The last few years have seen a boom in spectroscopic surveys of O stars, a consequence of the availability of modern instrumentation at telescopes of different apertures (from  $\sim 1$  m to  $\sim 10$  m) and the realization of the importance of high-quality data and large samples to characterize massive stars. These surveys differ from those in previous decades by their sample sizes, high S/N, and, in some cases, superior spectral resolving power and multi-epoch nature. Their usefulness is also helped by companion high-resolution imaging surveys to better characterize multiplicity (e.g. Maíz Apellániz 2010), the development of dedicated reduction pipelines, and, by the public availability of the reduced spectra. Table 1 lists the characteristics of some of those surveys. All of them include the blue-violet region of the spectrum traditionally used for spectral classification but some extend that towards the rest of the visible wavelengths.

Table 1. Current spectroscopic surveys with large samples of O stars

Acronym	Name	Principal Investigator(s)	Reference
GOSSS	Galactic O-Star Spectroscopic Survey	J. Maíz Apellániz	Maíz Apellániz et al. (2010)
OWN	Spectroscopic survey of Galactic O and WN stars	R. H. Barbá, N. I. Morrell, & R. C. Gamen	Barbá et al. (2010)
IACOB	IACOB spectroscopic survey	S. Simón-Díaz	Simón-Díaz et al. (2010)
NoMaDS	Northern Massive Dim Stars survey	A. Pellerin	This contribution
VFTS	VLT-FLAMES Tarantula Survey	C. Evans	Evans et al. (2010)
RIOTS4	Runaways and Isolated O-Type Star Spectroscopic Survey of the SMC	M. S. Oey & J. B. Lamb	Oey & Lamb (2011)
Gaia-ESO	Gaia-ESO spectroscopic survey	G. Gilmore & S. Randich	<a href="http://www.gaia-eso.eu">http://www.gaia-eso.eu</a>

  

Acronym	# of targets	# of O stars	Resol.	Sample	Spectral types	# of epochs	Fract. compl.
GOSSS	3000	1500	2500	Galactic N + S	O (+ B + WR + ...)	1-6	45%
OWN	300	250	15 000 - 48 000	Galactic S	O + WN	10	70%
IACOB	300	150	23 000 - 46 000	Galactic N	O + B	1-5	80%
NoMaDS	200	150	30 000	Galactic N	O (+ B + WR)	1-5	20%
VFTS	1000	250	7000	30 Doradus	O + B + ...	9	100%
RIOTS4	374	~130	2600	SMC field	O + B + WR	1-12	90%
Gaia-ESO	100 000	~100	20 000	Galactic clusters + field	All	1	0%

## 2. The Galactic O-Star Spectroscopic Survey (GOSSS)

The Galactic O-Star Spectroscopic Survey (GOSSS, Maíz Apellániz et al. 2010) is observing a sample of  $\sim 3000$  stars initially selected from a literature search of previous spectral classifications<sup>1</sup>. The main criterion for inclusion in the survey is the existence of at least one previous classification as spectral type O. It has currently observed over 1300 targets and our projections indicate that  $\sim 50\%$  of the objects in the full sample are indeed O stars; the rest are misclassifications due to low S/N data, incorrect classification techniques, insufficient resolution, or simple misidentifications. GOSSS has different quality checks to ensure that the data have good S/N (200 minimum,  $>300$  in most cases) and uniform spectral resolving power in the 3900-5100 Å classification range. The GOSSS data are being obtained at one telescope in the southern hemisphere (the 2.5 m du Pont at Las Campanas Observatory, Chile) and three telescopes in the northern hemisphere (the 1.5 m telescope at the Observatorio de Sierra Nevada, the 3.5 m telescope at Calar Alto, and the 4.2 m William Herschel Telescope at La Palma, all of them in Spain).

Compared to the other surveys in Table 1, GOSSS has two main differences: its final sample of O stars will be larger by an order of magnitude but its spectral resolving power will be significantly lower (with the exception of RIOTS4). Those are a consequence of the different philosophies behind the surveys. GOSSS aims to detect a large fraction of the O stars in the solar neighborhood by analyzing all good candidates down

<sup>1</sup>The search is ongoing and we keep adding stars.

to a given magnitude limit ( $B \sim 13$ ). A spectral resolving power of 2500 is sufficient to obtain accurate spectral types (and thus determine which ones are real O stars) but not to determine all physical parameters of interest such as  $v \sin i$ , detect SB2s with maximum velocity separations lower than  $\sim 150$  km/s, or to study the kinematics of the intervening ISM. The latter properties can be obtained with the higher resolution surveys, which are restricted to smaller samples of brighter stars (OWN, IACOB) or require more expensive time in larger telescopes (NoMaDS). Those larger telescopes are in some cases only accessible to large collaborations that target clusters with multi-fiber spectrographs (VFTS, Gaia-ESO); those programs can have large samples but only a minority of them are O stars. In summary, GOSSS excels at giving us better statistics and searching for interesting targets that can later be analyzed in more detail at higher resolution with the other surveys.

The first GOSSS results were published in a letter (Walborn et al. 2010) that introduced the new class of Ofc stars and presented two new examples of the rare Of?p class, NGC 1624-2 and CPD -28° 2561. The first main block of the survey (northern bright stars) was later published (Sota et al. 2011). A second letter (Walborn et al. 2011) about nitrogen-rich fast rotators is scheduled to appear later in 2011. A second block of the survey (southern bright stars) will be submitted later this year.

### 3. The Northern Massive Dim Stars (NoMaDS) survey

OWN (southern hemisphere) and IACOB (northern hemisphere) are the high-resolution counterparts of GOSSS in the sense of attempting to obtain spectra for all Galactic O stars (plus other massive stars) down to a given magnitude limit. OWN originally had an emphasis on the detection of SB2s and IACOB on the detailed modeling of physical parameters; later on, both surveys started a collaboration given their complementarity in coordinate coverage and the possibility of using the other one's data for their original purposes. However, given that those surveys use 2-m class telescopes and that they aim to obtain similar S/N (per resolution element) values with a spectral resolving power more than an order of magnitude higher, they are limited to a significantly brighter magnitude limit ( $B = 8 - 9$ ). That leaves outside their sample many interesting targets, such as NGC 1624-2 or those in the Cyg OB2 association.

In order to remedy that situation, we have started NoMaDS, a survey that complements OWN and IACOB by obtaining  $R = 30\,000$  optical spectra of northern massive stars down to  $B = 14$ . NoMaDS data are being obtained with the High Resolution Spectrograph at the Hobby-Eberly Telescope (HET), located at McDonald Observatory, Texas, USA. The large effective aperture of HET (9.2 m) allows the obtention of high-resolution spectra with S/N of 200-300 for stars much dimmer than those in OWN or IACOB with the same exposure time.

We have obtained spectra with HET for 40 stars in the first four months of the survey. In most cases we observed only a single epoch but for a few targets we observed up to four epochs. Among our first results, we have obtained the first high-resolution spectra ever of NGC 1624-2, the most extreme of the currently known Of?p stars. We have also followed the orbit of Cyg OB2-9 near its periastron passage of June 2011 and we have obtained separate spectral types for both components. We plan to continue NoMaDS during 2011 and 2012 until we obtain 250 spectra for 200 stars.

#### 4. The Galactic O-Star Catalog (GOSC)

The first published version (v1.0) of the Galactic O-Star Catalog (GOSC) originated with the 378-star sample of Maíz Apellániz et al. (2004), which was compiled from a collection of accurate spectral types from the literature (the vast majority of them coming from Nolan Walborn). This was later extended in v2.0 by Sota et al. (2008) to include 1208 objects, some of them not O stars, with spectral types of diverse origins and qualities. Subsequent small revisions extended the number of objects to 1285 in the last public version (v2.3.2, April 2011).

While analyzing the GOSSS spectra we realized that a significant fraction of the stars in v2.0 originally classified as being of O type were actually early-B stars or of even later type. Also, while writing Sota et al. (2011) we realized the need to introduce the spectral subtype O9.7 for luminosity classes V to III and to consequently tweak the spectral classification criteria for late-O and early-B stars. Those two issues led us to alter our policy regarding the addition of new stars to GOSC: We stopped adding new stars to the public version and instead created a private version that currently has 3000+ additional objects<sup>2</sup> and is used to generate the GOSSS sample. By keeping that version private our intention is to reduce the noise (in the form of poor-quality spectral classifications) until we can increase the signal. We will start doing that when we roll out v3.0 of GOSC in 2012 after we publish the second block of GOSSS (~200 bright southern stars). Version 3.0 will replace the old spectral types with the ones derived from GOSSS and will include the results from the first two GOSSS blocks. Additional spectral types will be added to GOSC when subsequent papers are published.

Other recent (last two years) and future changes to GOSC include:

- A simplified URL: <http://gosc.iaa.es>.
- A new interface that allows for searches and filters using a combination of IDL, Javascript, and MySQL.
- The possibility of selecting HTML, Aladin, and VOTable outputs.
- In the future we will use GOSC as the platform to disseminate the data from our surveys, including GOSSS, NoMaDS, and our AstraLux-based imaging surveys (Maíz Apellániz 2010).

#### 5. Marxist Ghost Buster (MGB)

The first author (J. M. A.) has written an IDL code called Marxist Ghost Buster (or MGB) as a companion to the GOSSS (and other) surveys in order to attack the spectral classification of the data. The code derives its name from attacking both classes (hence the Marxist part) and spectra<sup>3</sup> (hence the Ghost Buster part). The spectral classification is done by comparing the observed spectra with a standard library. The current beta version includes two libraries, both intended for classification of OB stars in the blue-violet region of the spectrum. The first library is built from GOSSS data at  $R \sim 2500$

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<sup>2</sup>Some are known to be massive non-O stars, others are unobservable by GOSSS because they are too dim in the  $B$  band or because they are not easily resolved from the ground.

<sup>3</sup>In the Latin meaning(s) of the word.

and is being used for the spectral classification of GOSSS itself. The second library has been compiled by Sergio Simón-Díaz (northern stars, from the IACOB survey) and Hughes Sana (southern stars, from a variety of sources), has a higher spectral resolving power ( $R \sim 4000$ ), and is being used for the spectral classification of a subset of the VFTS data. In any case, MGB is a general code that can be adapted for the spectral classification of other types of stars as long as a library is generated.

MGB is an interactive code where the user is allowed to change four parameters:

1. Spectral subtype.
2. Luminosity class.
3.  $n$  index (broadening).
4. Different standards for the same grid point in order to evaluate aspects such as ONC or  $f$  characteristics.

Additionally, it is possible to build synthetic binaries with different velocities and component types in order to fit SB2 spectra.

MGB is currently being tested. Its first public version will be released at the first author's web site (<http://jmaiz.iaa.es>) at or near the same time v3.0 of GOSC becomes available during 2012<sup>4</sup>.

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<sup>4</sup>And no, we do not believe that is another sign of the end of the world.